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THE GEOMAGNETIC OBSERVATORY ON TRISTAN DA CUNHA: SETUP, OPERATION AND EXPERIENCES

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ABSTRACT

The island Tristan da Cunha is located in the South Atlantic Anomaly, and until recently the area has been one of the largest gaps in the global geomagnetic observatory network. As part of the Danish project SAADAN we set up a geomagnetic observatory on the island. Here we report on how we established the observatory in 2009 and on its operation in 2010.

Keywords: Geomagnetic observatory, Tristan da Cunha, South Atlantic Magnetic Anomaly, South Atlantic Anomaly

1 INTRODUCTION

Tristan da Cunha, an island in the South Atlantic Ocean, is located in the South Atlantic Anomaly (SAA), which is the largest anomaly of the Earth's main field with low, and still decreasing, field intensity (e.g., Hulot et al., 2007). Despite this fact, the region has until recently been one of the largest gaps in the global distribution of geomagnetic observatories. As part of the project SAADAN (South Atlantic Anomaly Danish magnetic field project) funded by the Danish Agency for Science, Technology and Innovation through a grant from The Danish Council for Independent Research/Natural Sciences, a fully operational geomagnetic observatory was established on Tristan da Cunha in October 2009. This observatory is operated by DTU Space, Denmark, and has the IAGA code TDC. The scientific aim of the project is to study the main field in the SAA and its influence on ionospheric currents and induction effects in the region as well as the magnetospheric ring current in this longitudinal sector. In particular, the observatory data shall be used in conjunction with geomagnetic data from ESA's upcoming Swarm satellite mission (Friis-Christensen et al., 2006) and improve modelling of the SAA. Here we report on the observatory and its first year of operation.

2 OBSERVATORY

2.1 Location

The geomagnetic observatory Tristan da Cunha (IAGA code TDC) is located on a coastal plateau of the volcanic island Tristan da Cunha, on the golf course just beside the only village Edinburgh of the Seven Seas. The location was determined by GPS to be 37.07° S, 12.32° W and 42 m above sea level (WGS84).

The island is only accessible by sea with about ten ships per year coming from Cape Town, which takes about 5 days of sailing. Its harbour is only suitable for small boats or barges and often closed due to rough seas. The

South African research vessel SA Agulhas calls each September and gives visitors the opportunity to stay on the island for two to three weeks. The SA Agulhas carries helicopters, making passenger transport to Tristan less weather dependent. From a logistics point it is best to ship all important cargo ahead of the trip and sail on the SA Agulhas once all cargo is landed on the island.

The island is volcanic with strongly magnetised rocks, and the geomagnetic observatory was placed on the coastal plain with a smooth (and rather flat surface) to avoid magnetic gradients. The plain consists of horizontal lava flows overlain by volcanic sediments and soil. The remnant magnetisation of the volcanic material in the soil and sediment likely cancels out, so the magnetisation below the observatory should be mainly induced magnetisation. The location on the golf course was chosen to have maximum distance to the settlement, to the coast, and to a nearby gulch which carries volcanic gravel and boulders, see Figure 1. The coast and gulch were avoided because their topography could give rise to magnetic gradients and because erosion processes will move the magnetic volcanic material and thus change the local magnetic field bias. A preliminary total field survey of the area showed that the planned location had relatively small gradients compared to the area closer to the coast.

Figure 1. View from the South with the Tristan da Cunha absolute hut (centre). The edge of the gulch is shown on the left side in the foreground. Between the gulch and the absolute hut is the CTBTO monitoring station (approximately 140 meters from the absolute hut) and the settlement is to the east (approximately 110 meters). The variometer shelter was not yet established at that time.

2.2 Timeline

A first visit to Tristan da Cunha in 2004 for paleo- and geomagnetic investigations was used as a first assessment of possible observatory locations and test measurements (Matzka et al., 2009). A proposal for funding was submitted in September 2007 and granted in 2008. Initial plans to construct the observatory in September 2008 were postponed by one year after the local factory and generators were destroyed by fire in February 2008. In the mean time, a prefabricated absolute hut was designed at Hermanus Magnetic Observatory in South Africa and delivered by the SA Agulhas to Tristan da Cunha in September 2008. Under supervision of the company Enviroconsult, a scalar magnetometer survey of the observatory location was performed, the concrete foundation for this hut and for the pillars were laid, and the absolute hut was assembled in November

2008 and equipped with a continuously operating scalar magnetometer. A prefabricated variometer shelter, a variometer, one more scalar magnetometer, and a DI-flux were then shipped to Tristan da Cunha. In September three of us (BOH, AB, JM) visited Tristan to set up the variometer shelter, finalise the observatory, and train two persons from Tristan (RR and JJG). The regular observatory operations commenced in October 2009. A wireless network connection was established in October 2009 with intermittent success, and online data through a buried LAN-cable was successfully transmitted since December 2010. At the time of writing, an application for Intermagnet-status is prepared for the observatory.

2.3 Buildings and instruments

Grazing land on Tristan is scarce, and the observatory had to be designed as small as possible since this particular area is among the best grassland on the island. Another initial concern was that rodents might damage any underground cables that are buried between huts and could cause long data gaps before spare parts could be shipped to Tristan. Therefore, the observatory was designed to need only one hut (absolute hut) with the absolute instruments in one end and all electronic devices, such as power-supplies, data logger, and magnetometer electronics, on the other side. The absolute instruments and the electronic devices used were tested beforehand in this configuration to check that they did not disturb the absolute measurements.

Three underground, 150 m long power cables with surge protectors and breakers connect the absolute hut to the electricity grid, which is supplied by diesel generators. Instruments and data logger are all attached to one of the power cables with a 1000 VA uninterruptible power supply (UPS) connected to the grid, a second cable (no UPS) is used to power heating, light, and sockets in the observatory and the third cable is a spare. Later, an outdoor-capable Cat 5e LAN-cable was added for data transfer. The only other buried cables in this observatory design are for the variometer sensor, heating power, and temperature probe from the absolute hut to the variometer shelter, which are all protected in a PVC tube.

2.3.1 Materials, preparations, construction

The absolute hut (white hut on the right side of Figure 2a) was prefabricated (under supervision of DW) from standard marine plywood panels pre-treated with polyurethane marine grade primer. Assembled, it is 6.1 m long and 2.4 m broad and has a slightly inclined roof. Finally, it was treated with polyurethane marine grade white colour. The floor panels are mounted on a wooden ring beam, which is fixed with brass tie-down straps embedded in the concrete foundations. There are two strip foundations oriented approximately east-west and separated by 1.2 m, each is 6.5 m long, 0.6 m broad, and 0.4 m deep. The foundations were poured with the ring beam already set on top with the tie-down straps extending into the volume to be filled by the fluid concrete. Later the floor panels, the wall panels, an upper ring beam, and the roof panels were installed. The hut is additionally secured by stay wires made from non-magnetic stainless steel. There is a door on the eastern side of the hut (not shown), a pillar on the western side as shown in Figure 2d, a window facing south, and a removable panel in the wall to the west, also shown in figure 2d. The hut is oriented such that its north-east corner lies to magnetic east from this pillar, and the removable panel was dimensioned to allow for sun-observations during the late afternoon hours in the month of September.

A pallet with 64 aerated concrete blocks (150 mm*190 mm 590*mm) was shipped to Tristan da Cunha to build nonmagnetic, rigid, thermally insulating rodent-protected structures. The blocks are easily cut with a hand saw and glued with tile adhesive (50 kg) or epoxy resin (3 kg) for extra strength. They were used mainly for pillars above ground (Figures 2a and 2d) and to thermally insulate the variometer sensor (Figure 2c).

In Figure 2a the inner and outer foundation of the variometer shelter is shown. The gap between the foundations is filled with glass shards to block access from rodents. The black PVC tube (conduit) extending upwards from this gap protects the variometer's sensor cable and power cables for heating. Figure 2a also shows the variometer pillar (discussed later) made from aerated concrete blocks. Around this pillar, on top of the inner foundation, a shell was build from aerated concrete blocks to house the entire variometer sensor and plastered with mortar to improve its water resistance. This is the grey structure in the centre of Figure 2b. For heating, two electric heating mats (one as back up, each about 120 Watts) were wrapped around the lower part of the pillar in the gap between the central pillar and the surrounding shell of aerated concrete blocks. Above the pillar, there is a cavity large enough to house the variometer sensor, as seen in Figure 2c. In fact, the pillar plus the shell, both constructed of aerated concrete blocks, could be seen as one large pillar that is decoupled from the rest of the variometer shelter through its own foundation. This 'über'-pillar is housing, protecting, and thermally isolating the variometer and its temperature controlled heating unit.

For further protection against rain and wind, the aerated concrete structure is covered with a fibreglass shelter (Figures 2b and c) that is attached to the outer foundation (shown in Figure 2a). The shelter is pyramid-shaped (with a flat top) to withstand strong winds without the need for stay wires. The fibreglass shelter was prebuilt in South Africa (designed by DW). A wooden frame was constructed resembling a pyramid with flat roof. The frame was covered both inside and outside with plywood and the gaps in between filled with Isotherm (a polyester fleece) and painted inside. On the outside, the plywood was covered with four layers of lightweight fibreglass (chopped-strand mat), polyester-resin and finished with self-levelling polyester-resin mixed with white pigment for UV-protection and a high albedo (sunlight-reflection) for temperature stability.

Figure 2. (a) Foundation of the variometer shelter with variometer pillar (left) and absolute hut (right) seen from west during sun observation on variometer pillar. (b) Mortar covered aerated concrete structure to be covered by pyramid-shaped fibreglass shelter for wind and rain protection. (c) Fibreglass shelter with open access door shows aerated concrete structure with open access window and variometer sensor. (d) View inside the absolute hut from east: DI-flux on pillar, window towards south, removable panel in wall towards west, and scalar magnetometer in the upper south-west corner.

2.3.2 Pillars and instruments

There are three pillars established in the observatory; all are as high as possible to reduce magnetic field gradients. The DI-pillar in the absolute hut is the main pillar, and the observatory data is referenced to it. It holds a non-magnetic Zeiss 020B theodolite with circles in gon, converted by Mingeo (Hungary). Above it, two light bulbs are mounted to give sufficient light for reading the circles in all theodolite positions (Figure 2d). The FGE-pillar in the variometer shelter (described above) holds an observatory grade suspended variometer (ser. nr. 337) of type FGE (manufactured by DTU Space, Denmark). The three-axis sensor is oriented along local magnetic north. Both pillars have a concrete foundation (0.6 m by 0.6 m cross-section and 1 m deep) below ground level. To simplify logistics, (magnetic) sand and gravel from the island was used for mixing concrete since it was deemed unnecessary or even counterproductive to have non-magnetic subsurface structures in the magnetised ground. The concrete pillar foundations were cast in 2009 and thus had time to settle for one year before the pillars were extended with light and nonmagnetic aerated concrete blocks (0.3 m by 0.3 m cross-section) to a height of 1.2 m for the DI-pillar and 0.8 m for the FGE-pillar. To hold the instruments stable on the porous aerated concrete blocks, a glass tile with metal foot plates was cemented on top of these pillars. Gaps to prevent mechanical contact between the pillars and the remaining building were filled with silicone (absolute-hut) or glass shards (FGE-pillar). The PPM-pillar is not strictly a pillar. It is made from wood and fixed to the building wall just below the roof. It holds the sensor of a GSM-90FI Overhauser magnetometer (ser. nr. 8052740) but can also support a DI-flux in an equivalent position to approximately measure magnetic north (geographic north could not be determined) and inclination. Sun-observations were made on September 15, 2009, on both the DI-pillar (16 sun-shots using the circle engraved in the telescope, and 4 sun-shots waiting for the leading and trailing limb of the sun to touch the cross hair) and the FGE-pillar (16 sun-shots with circle). The results, either calculated by programs ASTRO83 and AZMSOLE (MICA ephemerides) or using the 'Danish' spreadsheet with internal calendar and with the Nautical Almanac, compare very well. UTC was determined with a handheld GPS and UT1 – UTC was 0.21 s. Four azimuth marks were established. The position of the pillars and azimuth marks are given in Table 1, determined with handheld GPS (set to WGS84) and checked for internal consistency with the available theodolite bearings in between the pillars and marks.

Table 1. Geodetic latitude, longitude and elevation of the Tristan da Cunha geomagnetic observatory, its pillars and azimuth marks

	lat. (°)	colat. (°)	long. W (°)	long. E (°)	height (m)
Observatory*	-37.067	127.067	12.315	347.685	42
DI-pillar	-37.06727	127.06727	12.31486	347.68514	42
FGE-pillar	-37.06725	127.06725	12.31503	347.68497	not determined
azim. mark 1	-37.06823	127.06823	12.31469	347.68531	not determined
azim. mark 2	-37.06839	127.06839	12.31497	347.68503	53
azim. mark 3	-37.06709	127.06709	12.31181	347.68819	39
azim. mark 4	not determined		not determined		not determined

(* Rounded value for DI-pillar)

Azimuth mark 1 was established first for the sun observations, and the azimuths to the other azimuth marks were determined later by turning angles. The azimuths of the marks as seen from the DI-pillar are given in Table 2. For the FGE-pillar, only the azimuth to azimuth mark 1 was determined (162° 55.610'). The standard deviation for the azimuth was varying from 4'' to 13'' for the various sets of sun-shots.

Table 2. Azimuth of azimuth marks as seen from DI-pillar

mark	azimuth	description	visible trough
azim. mark 1	170° 32.88'	geodetic mark on building, 110 m from DI-pillar	window
azim. mark 2	185° 22.44'	left-side edge of container	window
azim. mark 3	85° 36.49'	spindle of the weather vane between arrows and whale on the tower of Catholic Church St. Josephs	door
azim. mark 4	88° 09.34'	knob in Main Cliff's vertical rock face on the same height as azimuth mark 1	door

Magnetic declination (D), inclination (I), and total field strength (F) were determined on the DI-pillar and FGE-pillar simultaneously, following the scheme F-D-I-D-F usually used for repeat stations (Newitt et al., 1996). Later, inclination and total field strength were determined on the DI-pillar and the PPM-pillar simultaneously. The mean pillar differences are given in Table 3; approximate values for the time of the measurements are horizontal component H = 10640 nT and the vertical field component Z = -22540 nT.

Table 3. Pillar differences between the DI-pillar and FGE-pillar as well as between the DI-pillar and the FGE-pillar.

	ΔD (')	ΔH (nT)	ΔZ (nT)	ΔF (nT)
DI-pillar minus FGE-pillar	-17.8	314.4	-57.8	185.2
DI-pillar minus PPM-pillar		-14.4	14.7	7.7

2.3.3 Data logger and heating control

Three data logger units were set up: the 'Hungarian' system (Magrec 4), the 'Norwegian' system, and the 'Danish' system. Employing different data loggers is work intensive and would not be justified for the sake of redundancy alone. However, each of the three systems has very specific advantages, and we can compare their suitability for remote operations. The Danish system is a Windows XP laptop with self-developed visual basic software (by LWP) and is used as the main logger with 1 Hz for definitive data at DTU Space. The system is flexible and allows adding certain components, like the logging of the scalar-magnetometer (GSM-90) or the control of the heating power for the variometer. Disadvantages are the time keeping, which was at first done manually twice per week ahead of the absolute measurements and only after 2010 by a time server through the internet connection. The Norwegian system is a Linux computer with internet connection and 0.1 Hz data collection. The system is well adapted to online data transmission and was connected to the internet from the beginning. This system is used to send preliminary data to the Kyoto Intermagnet Geomagnetic Information Node. The Hungarian system is a 24-bit system with 16 Hz, and it has a very accurate time stamping based on the GPS pps. This system was very useful during the set up of the observatory since the online display of high resolution data allowed noise identification on the variometer channels. Connecting the three data loggers in parallel to the analogue output of the variometer might disturb the analogue signal from the variometer. Therefore, a special electronic buffer-box was built at the University of Tromsø. This buffer has three analogue outputs, each acting as a gain-one-amplifier to the analogue variometer output.

The electric heating in the variometer box is regulated by the Danish data logger system (laptop), which already digitizes the three variometer channels, the sensor temperature, and the variometer electronics temperature at 1 Hz. Every minute the sensor temperature is compared to a set point temperature, and the heating is turned off when the set point is exceeded (and vice versa) by a solid state relay controlled by the laptop. This simple mechanism provides surprisingly stable regulation of the temperature, but the computer could malfunction while the heating power is switched on. To prevent overheating of the variometer sensor, a commercial temperature control switches the heating power off when the temperature exceeds the normal set point by 10°C. This back-up system produces significant spikes when switching and cannot be used for normal temperature regulation.

The data logger and heat have the highest power consumption in the observatory, but the total power consumption is less than 2000 kWh per year (about 200 Watt mean consumption).

2.4 Training

Prior to their training in DI-flux measurements, the local observers were involved with magnetic measurements and observatory routine for about one year, including a first scalar magnetometer survey of the planned observatory location and the continuous operation of a GSM-19 Overhauser magnetometer. This involved magnetic cleanliness, regular manual data transfer by email, timekeeping procedures, and keeping a log and was thus very good preparation for absolute measurements. After the observatory was completed in September 2009, there was comparatively little time for training with the DI-flux, but during the first weeks of independent measurements and feed back to the observers the number of errors gradually became smaller.

3 OPERATIONS

In 2010, about 15 absolute measurements per month were made by two observers (station manager RR and JG) to keep both well trained. The results of two different observers can be checked against each other, and the two observers are a back up for each other if one has to leave the island, which would mean an extended period of absence. The DI-flux measurements are performed using the residual method (Kring Lauridsen, 1985). The calculations are performed both by Excel-spreadsheets and by a Matlab script that are routinely used at the Danish and Greenlandic geomagnetic observatories, with some modifications to account for the negative inclination. These modifications were tested beforehand with absolute measurements at the Hermanus Magnetic Observatory. The baselines presented here are neglecting the total field difference of 7.7 nT between the DI-pillar and the PPM-pillar, and the field differences between the DI-pillar and the FGE-pillar are not accounted for.

Out of the 176 absolute measurements in 2010, 8 measurements had to be discarded because of observers being magnetic, missing variometer or scalar data, or because of errors in the DI-flux measurements. Another 21 measurements were at first giving unreasonable baselines and unreasonable theodolite parameters (i.e., sensor offset, horizontal collimation, vertical collimation, difference between sensor up and sensor down inclination). In this case, the specific circle reading responsible for the unreasonable theodolite parameter was identified by comparison with readings from previous measurements (taking into account the size of the residual and geomagnetic field changes as measured by the variometer). The suspicious DI-flux circle reading was then manipulated in a simple way (e.g., by changing a circle reading by 1, 0.1 or 0.05 gon) and only adopted if it resulted in reasonable theodolite parameters. This somewhat tedious procedure was applied not only to understand what kind of errors were made by the observers and give them advice remotely but also to have an up-to-date check to be sure the instruments were still in order. The resulting baselines are shown (as crosses) in comparison to good absolute measurements (dots) in Figure 3.

There are two sets of H-baselines (H0) shown in Figure 3: before (red) and after (black) a temperature correction to the magnetic north channel of the variometer by -0.15 nT/°C. Unfortunately, there is no special temperature control of variometer electronics, and the temperature can change by 5 to10 degrees during one day. A comparison of the baseline H0 and the electronics temperature throughout the year (blue background in Figure 3) suggests a temperature dependency of 0.22 nT/°C. The difference between the scalar magnetometer and the computed total field can be made independently of the electronics temperature when accounting for a temperature dependency of 0.12 nT/°C. However, this lower estimate might be caused by a counteracting temperature dependency of the vertical downwards channel of the variometer. From these observations, we adopted the temperature correction of -0.15 nT/°C to the magnetic north channel and estimate that this could be in error by 0.07 nT/°C at most and the vertical down channel could have a temperature dependency in the order of 0.05 nT/°C at most. Assuming a daily temperature variation of 10 °C, the errors should be limited to 0.7 nT in H and 0.5 nT in Z. Neither the baselines for Z nor D show a dependency on the electronics temperature throughout the year.

The temperature of the variometer sensor is usually stable within 0.13 °C. There were six episodes in 2010 when the sensor temperature changed due to temperature control failure or power outage, each indicated by a vertical line in Figure 3. This can either lead to a higher (when the regulating relays remain on) or lower (relays off or power outage) temperature and is usually accompanied with a data gap (about 10 days data during 2010 are lost because of data gaps or unstable temperature). Despite these events, the baseline is stable throughout the year as seen in Figure 3.

The laptop of the ‘Danish’ data logger system (introduced in September 2009 as a last minute change to the otherwise magnetically tested equipment) was found to cause a magnetic field at the location of the absolute instruments. It was replaced by a nonmagnetic computer with solid state hard disk during a maintenance visit in January 2011. Also the variometer electronics was replaced with a lower noise fluxgate electronics.

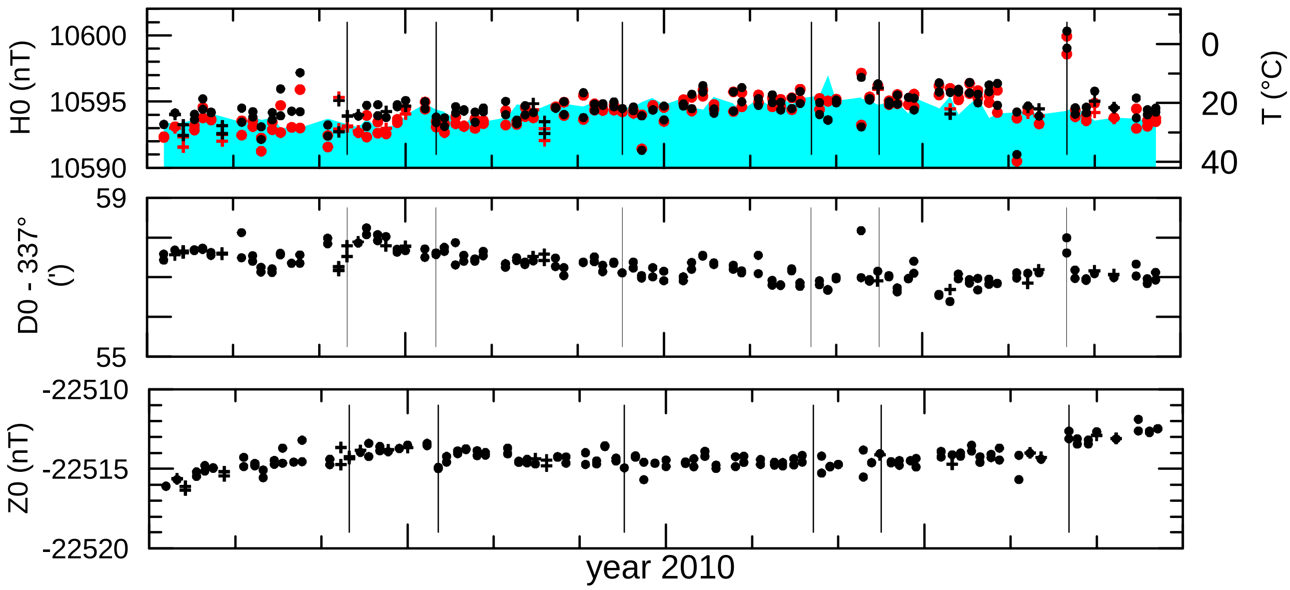

Figure 3. Baselines H0, D0, and Z0 for Tristan da Cunha geomagnetic observatory for the year 2010. H0 is shown before (red) and after (black) a temperature correction of the horizontal north channel of the variometer. Variometer electronics temperature is shown in blue (inverted scale). Some unreasonable absolute measurements were corrected (see text for details) and are shown as crosses.

4 CONCLUSION

A geomagnetic observatory was established in one of the most scientifically interesting regions on Earth ahead of the upcoming Swarm satellite mission.

Despite the remoteness and volcanic nature of Tristan da Cunha, the geomagnetic observatory delivers data with good baselines. There were several occasions in 2010 with data gaps of a few days.

The pyramid-shaped variometer shelter with the aerated concrete shell inside proved a very good concept, resulting in stable sensor temperature with low power consumption. The construction is strong and stable without stay wires.

The compact absolute hut design that also houses all electronic devices is serving its purpose well. However, everything installed in the hut must be tested to be sufficiently non-magnetic.

Currently a non-magnetic, temperature controlled enclosure for the FGE-electronics is under development at DTU Space. This enclosure will be useful to stabilise the variometer-electronics temperature at Tristan da Cunha in the future.

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